

Express Mail" mailing label number EL 782718917 US

Date of Deposit: May 3, 2001

I hereby certify that this paper or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" under 37 CFR § 1.10 on the date indicated above and is addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231.

Jose Ramos

## UNITED STATES PATENT APPLICATION

FOR

# LOW SIGNAL-TO-NOISE RATIO POSITIONING SYSTEM

### INVENTORS:

Todd V. Townsend  
Sergey Lyusin

### PREPARED BY:

Coudert Brothers  
333 South Hope Street  
Twenty - Third Floor  
Los Angeles, CA 90071  
(213) 229-2900

Applicant hereby claims priority to provisional patent application 60/201,625 filed May 3, 2000.

## BACKGROUND OF THE INVENTION

### 1. FIELD OF THE INVENTION

5

The present invention relates to locating the position of an object, and in particular embodiments of the present invention are directed toward using a satellite positioning system to locate the position of objects that are obstructed.

### 2. BACKGROUND ART

People use positioning systems to precisely determine the locations of objects. One type of positioning system is the Global Positioning System (GPS) and uses multiple satellites that orbit the earth. The satellites transmit signals to earth that can be detected by anyone with a receiver. Currently, however, it is impossible to track objects using the receiver when the object is obstructed, for instance within an enclosed structure such as a parking garage or building, or under a tree or bridge. Before further discussing the drawbacks associated with current positioning systems, it is instructive to discuss navigation generally.

20

#### Navigation

Since the beginning of recorded time, people have been trying to figure out a reliable way to determine their own position to help guide them to where they are going and to get them back

home again. On land people relied on maps, landmarks, and local residents to navigate. There are no landmarks or residents on the ocean, however, so sea travel was particularly difficult. To avoid getting lost, early sailors followed the coastline closely, rarely going out of sight of land. When humankind first sailed into the open ocean, they used the stars to chart their path. The north star was used in the northern hemisphere but was not available once a ship was too far south of the equator. The compass was also used to determine the direction of North but could only provide direction information, but not position information. Eventually clocks were developed that could be used at sea so that longitudinal (east west) directions could be determined.

Still, however, it was impossible to exactly where you were with any precision. In modern times, the need and desire to know the exact location on sea or land within meters arose. Military, commercial, and personal requirements created the need for more accurate positioning systems. In the early 20th century ground based radio navigation systems were developed. One drawback of using a ground based radio system is the tradeoff between coverage and accuracy. High-frequency radio waves provide accurate position location but can only be picked up in a small, localized area. Lower frequency radio waves cover a larger area, but cannot pinpoint the location of an object with precision.

### Satellite Positioning System

To partially solve the problems associated with ground-based navigation systems, high-frequency radio transmitters were placed in space as part of the GPS system. As is well known,

GPS was established by the United States government, and employs a constellation of satellites in orbit around the earth at an altitude of approximately 26500 km. Currently, the GPS constellation consists of 24 satellites, arranged with 4 satellites in each of 6 orbital planes. Each orbital plane is inclined to the earth's equator by an angle of approximately 55 degrees.

5

Each GPS satellite transmits microwave L-band radio signals continuously in two frequency bands, centered at 1575.42 MHz and 1227.6 MHz., denoted as L1 and L2 respectively. The GPS L1 signal is quadri-phase modulated by a coarse/acquisition code ("C/A code") and a precision ranging code ("P-code"). The L2 signal is binary phase shift key ("BPSK") modulated by the P-code. The GPS C/A code is a gold code that is specific to each satellite, and has a symbol rate of 1.023 MHz. The unique content of each satellite's C/A code is used to identify the source of a received signal. The P-code is also specific to each satellite and has a symbol rate of 10.23 MHz. The GPS satellite transmission standards are set forth in detail by the Interface Control Document GPS (200), dated 1993, a revised version of a document first published in 1983.

Another satellite positioning system is called GLONASS. GLONASS was established by the former Soviet Union and operated by the Russian Space Forces. The GLONASS constellation consists of 24 satellites arranged with 8 satellites in each of 3 orbital planes. Each orbital plane is inclined to the earth's equator by an angle of approximately 64.8 degrees. The altitude of the GLONASS satellites is approximately 19100 km.

0046954-05035  
T06050-4563480

The satellites of the GLONASS radio navigation system transmit signals in the frequency band near 1602 MHz, and signals in a secondary band near 1246 MHz, denoted as L1 and L2 respectively. The GLONASS L1 signal is quadri-phase modulated by a C/A code and a P-code. The L2 signal is BPSK modulated by the P-code. Unlike GPS, in which all of the satellites transmit on the same nominal frequency, the GLONASS satellites each transmit at a unique frequency in order to differentiate between the satellites. The GLONASS L1 carrier frequency is equal to  $1602 \text{ MHz} + k * 0.5625 \text{ MHz}$ , where  $k$  is a number related to the satellite number. The GLONASS L2 carrier frequency is equal to  $1246 \text{ MHz} + k * 0.5625 \text{ MHz}$ . The GLONASS C/A code consists of a length 511 linear maximal sequence. Details of the GLONASS signals may be found in the Global Satellite Navigation System GLONASS--Interface Control Document of the RTCA Paper No. 518-91/SC159-317, approved by the Glavkosmos Institute of Space Device Engineering, the official former USSR GLONASS responsible organization.

In addition to transmitting high frequency signals, both satellite systems send navigation messages and ephemeris data. The navigation message is a low frequency signal that identifies the satellite and provides other information. The ephemeris data provides information on the path and position of the satellite.

### Current Receivers

Conventional receivers, called GPS or SPS receivers, work well when the signals travel directly from the satellite to the receiver with no obstructions in the way. When passing under trees, bridges, through garages and when the receiver is in a building, however, problems occur.

Specifically, these objects present barriers that interfere with the signal and weaken it. Even worse, the navigation message, which is typically more difficult to detect than the signals, is often undetectable when there are obstructions.

5 Secondly, the receiver relies on detecting reflected signals. Obstructions between the signal sent by the satellite and the receiver compromise the signal path.. The signal reflects off nearby surfaces and then to the receiver. Some of these signals may be stronger than another, even though the distance the signal travels is further, depending on the reflecting surface or surfaces. This extra distance traveled by the signal can introduce errors into the distance and location calculations.

It is desirable to overcome this difficulty for a variety of reasons. First, it would be desirable to locate an object in a building in order to allow the users of positioning devices to obtain a fix and assess position-related data to access nearby services. Second, federal mandates may require the ability to locate cell phone users to a high degree of accuracy (e.g. within 100 feet) so that 911 services can locate an emergency caller even when the cell phone is used in a building or obstructed area. It would be desirable to provide a SPS receiver to overcome the above problems.

## SUMMARY OF THE INVENTION

Embodiments of the present invention relate to a low signal-to-noise ratio positioning system. According to one or more embodiments of the present invention, the receiver in a  
5 conventional positioning system is configured to communicate with a terrestrial broadcast station. The terrestrial broadcast station transmits assistance signals to the receiver and enable the receiver to locate very weak signals being transmitted from the satellites in the positioning system.

In one embodiment, the assistance signals include Doppler frequencies for the satellites. In another embodiment, the assistance signals include Ephemeris data. In another embodiment, the assistance signals include almanac data. Almanac data is a list of satellites that a particular receiver should be able to access currently. This prevents the receiver from searching for satellites, for instance, that are below the horizon and not currently usable. In other  
10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 195 200 205 210 215 220 225 230 235 240 245 250 255 260 265 270 275 280 285 290 295 300 305 310 315 320 325 330 335 340 345 350 355 360 365 370 375 380 385 390 395 400 405 410 415 420 425 430 435 440 445 450 455 460 465 470 475 480 485 490 495 500 505 510 515 520 525 530 535 540 545 550 555 560 565 570 575 580 585 590 595 600 605 610 615 620 625 630 635 640 645 650 655 660 665 670 675 680 685 690 695 700 705 710 715 720 725 730 735 740 745 750 755 760 765 770 775 780 785 790 795 800 805 810 815 820 825 830 835 840 845 850 855 860 865 870 875 880 885 890 895 900 905 910 915 920 925 930 935 940 945 950 955 960 965 970 975 980 985 990 995 1000 1005 1010 1015 1020 1025 1030 1035 1040 1045 1050 1055 1060 1065 1070 1075 1080 1085 1090 1095 1100 1105 1110 1115 1120 1125 1130 1135 1140 1145 1150 1155 1160 1165 1170 1175 1180 1185 1190 1195 1200 1205 1210 1215 1220 1225 1230 1235 1240 1245 1250 1255 1260 1265 1270 1275 1280 1285 1290 1295 1300 1305 1310 1315 1320 1325 1330 1335 1340 1345 1350 1355 1360 1365 1370 1375 1380 1385 1390 1395 1400 1405 1410 1415 1420 1425 1430 1435 1440 1445 1450 1455 1460 1465 1470 1475 1480 1485 1490 1495 1500 1505 1510 1515 1520 1525 1530 1535 1540 1545 1550 1555 1560 1565 1570 1575 1580 1585 1590 1595 1600 1605 1610 1615 1620 1625 1630 1635 1640 1645 1650 1655 1660 1665 1670 1675 1680 1685 1690 1695 1700 1705 1710 1715 1720 1725 1730 1735 1740 1745 1750 1755 1760 1765 1770 1775 1780 1785 1790 1795 1800 1805 1810 1815 1820 1825 1830 1835 1840 1845 1850 1855 1860 1865 1870 1875 1880 1885 1890 1895 1900 1905 1910 1915 1920 1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050 2055 2060 2065 2070 2075 2080 2085 2090 2095 2100 2105 2110 2115 2120 2125 2130 2135 2140 2145 2150 2155 2160 2165 2170 2175 2180 2185 2190 2195 2200 2205 2210 2215 2220 2225 2230 2235 2240 2245 2250 2255 2260 2265 2270 2275 2280 2285 2290 2295 2300 2305 2310 2315 2320 2325 2330 2335 2340 2345 2350 2355 2360 2365 2370 2375 2380 2385 2390 2395 2400 2405 2410 2415 2420 2425 2430 2435 2440 2445 2450 2455 2460 2465 2470 2475 2480 2485 2490 2495 2500 2505 2510 2515 2520 2525 2530 2535 2540 2545 2550 2555 2560 2565 2570 2575 2580 2585 2590 2595 2600 2605 2610 2615 2620 2625 2630 2635 2640 2645 2650 2655 2660 2665 2670 2675 2680 2685 2690 2695 2700 2705 2710 2715 2720 2725 2730 2735 2740 2745 2750 2755 2760 2765 2770 2775 2780 2785 2790 2795 2800 2805 2810 2815 2820 2825 2830 2835 2840 2845 2850 2855 2860 2865 2870 2875 2880 2885 2890 2895 2900 2905 2910 2915 2920 2925 2930 2935 2940 2945 2950 2955 2960 2965 2970 2975 2980 2985 2990 2995 3000 3005 3010 3015 3020 3025 3030 3035 3040 3045 3050 3055 3060 3065 3070 3075 3080 3085 3090 3095 3100 3105 3110 3115 3120 3125 3130 3135 3140 3145 3150 3155 3160 3165 3170 3175 3180 3185 3190 3195 3200 3205 3210 3215 3220 3225 3230 3235 3240 3245 3250 3255 3260 3265 3270 3275 3280 3285 3290 3295 3300 3305 3310 3315 3320 3325 3330 3335 3340 3345 3350 3355 3360 3365 3370 3375 3380 3385 3390 3395 3400 3405 3410 3415 3420 3425 3430 3435 3440 3445 3450 3455 3460 3465 3470 3475 3480 3485 3490 3495 3500 3505 3510 3515 3520 3525 3530 3535 3540 3545 3550 3555 3560 3565 3570 3575 3580 3585 3590 3595 3600 3605 3610 3615 3620 3625 3630 3635 3640 3645 3650 3655 3660 3665 3670 3675 3680 3685 3690 3695 3700 3705 3710 3715 3720 3725 3730 3735 3740 3745 3750 3755 3760 3765 3770 3775 3780 3785 3790 3795 3800 3805 3810 3815 3820 3825 3830 3835 3840 3845 3850 3855 3860 3865 3870 3875 3880 3885 3890 3895 3900 3905 3910 3915 3920 3925 3930 3935 3940 3945 3950 3955 3960 3965 3970 3975 3980 3985 3990 3995 4000 4005 4010 4015 4020 4025 4030 4035 4040 4045 4050 4055 4060 4065 4070 4075 4080 4085 4090 4095 4100 4105 4110 4115 4120 4125 4130 4135 4140 4145 4150 4155 4160 4165 4170 4175 4180 4185 4190 4195 4200 4205 4210 4215 4220 4225 4230 4235 4240 4245 4250 4255 4260 4265 4270 4275 4280 4285 4290 4295 4300 4305 4310 4315 4320 4325 4330 4335 4340 4345 4350 4355 4360 4365 4370 4375 4380 4385 4390 4395 4400 4405 4410 4415 4420 4425 4430 4435 4440 4445 4450 4455 4460 4465 4470 4475 4480 4485 4490 4495 4500 4505 4510 4515 4520 4525 4530 4535 4540 4545 4550 4555 4560 4565 4570 4575 4580 4585 4590 4595 4600 4605 4610 4615 4620 4625 4630 4635 4640 4645 4650 4655 4660 4665 4670 4675 4680 4685 4690 4695 4700 4705 4710 4715 4720 4725 4730 4735 4740 4745 4750 4755 4760 4765 4770 4775 4780 4785 4790 4795 4800 4805 4810 4815 4820 4825 4830 4835 4840 4845 4850 4855 4860 4865 4870 4875 4880 4885 4890 4895 4900 4905 4910 4915 4920 4925 4930 4935 4940 4945 4950 4955 4960 4965 4970 4975 4980 4985 4990 4995 5000 5005 5010 5015 5020 5025 5030 5035 5040 5045 5050 5055 5060 5065 5070 5075 5080 5085 5090 5095 5100 5105 5110 5115 5120 5125 5130 5135 5140 5145 5150 5155 5160 5165 5170 5175 5180 5185 5190 5195 5200 5205 5210 5215 5220 5225 5230 5235 5240 5245 5250 5255 5260 5265 5270 5275 5280 5285 5290 5295 5300 5305 5310 5315 5320 5325 5330 5335 5340 5345 5350 5355 5360 5365 5370 5375 5380 5385 5390 5395 5400 5405 5410 5415 5420 5425 5430 5435 5440 5445 5450 5455 5460 5465 5470 5475 5480 5485 5490 5495 5500 5505 5510 5515 5520 5525 5530 5535 5540 5545 5550 5555 5560 5565 5570 5575 5580 5585 5590 5595 5600 5605 5610 5615 5620 5625 5630 5635 5640 5645 5650 5655 5660 5665 5670 5675 5680 5685 5690 5695 5700 5705 5710 5715 5720 5725 5730 5735 5740 5745 5750 5755 5760 5765 5770 5775 5780 5785 5790 5795 5800 5805 5810 5815 5820 5825 5830 5835 5840 5845 5850 5855 5860 5865 5870 5875 5880 5885 5890 5895 5900 5905 5910 5915 5920 5925 5930 5935 5940 5945 5950 5955 5960 5965 5970 5975 5980 5985 5990 5995 6000 6005 6010 6015 6020 6025 6030 6035 6040 6045 6050 6055 6060 6065 6070 6075 6080 6085 6090 6095 6100 6105 6110 6115 6120 6125 6130 6135 6140 6145 6150 6155 6160 6165 6170 6175 6180 6185 6190 6195 6200 6205 6210 6215 6220 6225 6230 6235 6240 6245 6250 6255 6260 6265 6270 6275 6280 6285 6290 6295 6300 6305 6310 6315 6320 6325 6330 6335 6340 6345 6350 6355 6360 6365 6370 6375 6380 6385 6390 6395 6400 6405 6410 6415 6420 6425 6430 6435 6440 6445 6450 6455 6460 6465 6470 6475 6480 6485 6490 6495 6500 6505 6510 6515 6520 6525 6530 6535 6540 6545 6550 6555 6560 6565 6570 6575 6580 6585 6590 6595 6600 6605 6610 6615 6620 6625 6630 6635 6640 6645 6650 6655 6660 6665 6670 6675 6680 6685 6690 6695 6700 6705 6710 6715 6720 6725 6730 6735 6740 6745 6750 6755 6760 6765 6770 6775 6780 6785 6790 6795 6800 6805 6810 6815 6820 6825 6830 6835 6840 6845 6850 6855 6860 6865 6870 6875 6880 6885 6890 6895 6900 6905 6910 6915 6920 6925 6930 6935 6940 6945 6950 6955 6960 6965 6970 6975 6980 6985 6990 6995 7000 7005 7010 7015 7020 7025 7030 7035 7040 7045 7050 7055 7060 7065 7070 7075 7080 7085 7090 7095 7100 7105 7110 7115 7120 7125 7130 7135 7140 7145 7150 7155 7160 7165 7170 7175 7180 7185 7190 7195 7200 7205 7210 7215 7220 7225 7230 7235 7240 7245 7250 7255 7260 7265 7270 7275 7280 7285 7290 7295 7300 7305 7310 7315 7320 7325 7330 7335 7340 7345 7350 7355 7360 7365 7370 7375 7380 7385 7390 7395 7400 7405 7410 7415 7420 7425 7430 7435 7440 7445 7450 7455 7460 7465 7470 7475 7480 7485 7490 7495 7500 7505 7510 7515 7520 7525 7530 7535 7540 7545 7550 7555 7560 7565 7570 7575 7580 7585 7590 7595 7600 7605 7610 7615 7620 7625 7630 7635 7640 7645 7650 7655 7660 7665 7670 7675 7680 7685 7690 7695 7700 7705 7710 7715 7720 7725 7730 7735 7740 7745 7750 7755 7760 7765 7770 7775 7780 7785 7790 7795 7800 7805 7810 7815 7820 7825 7830 7835 7840 7845 7850 7855 7860 7865 7870 7875 7880 7885 7890 7895 7900 7905 7910 7915 7920 7925 7930 7935 7940 7945 7950 7955 7960 7965 7970 7975 7980 7985 7990 7995 8000 8005 8010 8015 8020 8025 8030 8035 8040 8045 8050 8055 8060 8065 8070 8075 8080 8085 8090 8095 8100 8105 8110 8115 8120 8125 8130 8135 8140 8145 8150 8155 8160 8165 8170 8175 8180 8185 8190 8195 8200 8205 8210 8215 8220 8225 8230 8235 8240 8245 8250 8255 8260 8265 8270 8275 8280 8285 8290 8295 8300 8305 8310 8315 8320 8325 8330 8335 8340 8345 8350 8355 8360 8365 8370 8375 8380 8385 8390 8395 8400 8405 8410 8415 8420 8425 8430 8435 8440 8445 8450 8455 8460 8465 8470 8475 8480 8485 8490 8495 8500 8505 8510 8515 8520 8525 8530 8535 8540 8545 8550 8555 8560 8565 8570 8575 8580 8585 8590 8595 8600 8605 8610 8615 8620 8625 8630 8635 8640 8645 8650 8655 8660 8665 8670 8675 8680 8685 8690 8695 8700 8705 8710 8715 8720 8725 8730 8735 8740 8745 8750 8755 8760 8765 8770 8775 8780 8785 8790 8795 8800 8805 8810 8815 8820 8825 8830 8835 8840 8845 8850 8855 8860 8865 8870 8875 8880 8885 8890 8895 8900 8905 8910 8915 8920 8925 8930 8935 8940 8945 8950 8955 8960 8965 8970 8975 8980 8985 8990 8995 9000 9005 9010 9015 9020 9025 9030 9035 9040 9045 9050 9055 9060 9065 9070 9075 9080 9085 9090 9095 9100 9105 9110 9115 9120 9125 9130 9135 9140 9145 9150 9155 9160 9165 9170 9175 9180 9185 9190 9195 9200 9205 9210 9215 9220 9225 9230 9235 9240 9245 9250 9255 9260 9265 9270 9275 9280 9285 9290 9295 9300 9305 9310 9315 9320 9325 9330 9335 9340 9345 9350 9355 9360 9365 9370 9375 9380 9385 9390 9395 9400 9405 9410 9415 9420 9425 9430 9435 9440 9445 9450 9455 9460 9465 9470 9475 9480 9485 9490 9495 9500 9505 9510 9515 9520 9525 9530 9535 9540 9545 9550 9555 9560 9565 9570 9575 9580 9585 9590 9595 9600 9605 9610 9615 9620 9625 9630 9635 9640 9645 9650 9655 9660 9665 9670 9675 9680 9685 9690 9695 9700 9705 9710 9715 9720 9725 9730 9735 9740 9745 9750 9755 9760 9765 9770 9775 9780 9785 9790 9795 9800 9805 9810 9815 9820 9825 9830 9835 9840 9845 9850 9855 9860 9865 9870 9875 9880 9885 9890 9895 9900 9905 9910 9915 9920 9925 9930 9935 9940 9945 9950 9955 9960 9965 9970 9975 9980 9985 9990 9995 10000 10005 10010 10015 10020 10025 10030 10035 10040 10045 10050 10055 10060 10065 10070 10075 10080 10085 10090 10095 10100 10105 10110 10115 10120 10125 10130 10135 10140 10145 10150 10155 10160 10165 10170 10175 10180 10185 10190 10195 10200 10205 10210 10215 10220 10225 10230 10235 10240 10245 10250 10255 10260 10265 10270 10275 10280 10285 10290 10295 10300 10305 10310 10315 10320 10325 10330 10335 10340 10345 10350 10355 10360 10365 10370 10375 10380 10385 10390 10395 10400 10405 10410 10415 10420 10425 10430 10435 10440 10445 10450 10455 10460 10465 10470 10475 10480 10485 10490 10495 10500 10505 10510 10515 10520 10525 10530 10535 10540 10545 10550 10555 10560 10565 10570 10575 10580 10585 10590 10595 10600 10605 10610 10615 10620 10625 10630 10635 10640 10645 10650 10655 10660 10665 10670 10675 10680 10685 10690 10695 10700 10705 10710 10715 10720 10725 10730 10735 10740 10745 10750 10755 10760 10765 10770 10775 10780 10785 10790 10795 10800 10805 10810 10815 10820 10825 10830 10835 10840 10845 10850 10855 10860 10865 10870 10875 10880 10885 10890 10895 10900 10905 10910 10915 10920 10925 10930 10935 10940 10945 10950 10955 10960 10965 10970 10975 10980 10985 10990 10995 11000 11005 11010 11015 11020 11025 11030 11035 11040 11045 11050 11055 11060 11065 11070 11075 11080 11085 11090 11095 11100 11105 11110 11115 11120 11125 11130 11135 11140 11145 11150 11155 11160 11165 11170 11175 11180 11185 11190 11195 11200 11205 11210 11215 11220 11225 11230 11235 11240 11245 11250 11255 11260 11265 11270 11275 11280 11285 11290 11295 11300 11305 11310 11315 11320 11325 11330 11335 11340 11345 11350 11355 11360 11365 11370 11375 11380 11385 11390 11395 11400 11405 11410 11415 11420 11425 11430 11435 11440 11445 11450 11455 11460 11465 11470 11475 11480 11485 11490 11495 11500 11505 11510 11515 11520 11525 11530 11535 11540 11545 11550 11555 11560 11565 11570 11575 11580 11585 11590 11595 11600 11605 11610 11615 11620 11625 11630 11635 11640 11645 11650 11655 11660 11665 11670 11675 11680 11685 11690 11695 11700 11705 11710 11715 11720 11725 11730 11735 11740 11745 11750 11755 11760 11765 11770 11775 11780 11785 11790 11795 11800 11805 11810 11815 11820 11825 11830 11835 11840 11845 11850 11855 11860 11865 11870 11875 11880 11885 11890 11895 11900 11905 11910 11915 11920 11925 11930 11935 11940 1194

maintain a lock even when it does not have a strong enough signal acquisition to independently decode needed data.

09848954.050301  
F0E050"45684860



## BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects and advantages of the present invention will become better understood with regard to the following description, appended claims and accompanying  
5 drawings where:

Figure 1 is a low signal-to-noise ratio positioning system according to an embodiment of the present invention.

Figure 2 shows the use of an assistance signal according to an embodiment of the present invention.

Figure 3 shows the use of an assistance signal according to another embodiment of the present invention.

Figure 4 shows the use of an assistance signal according to another embodiment of the present invention.

Figure 5 is a digital message from a satellite to a receiver according to an embodiment of  
20 the present invention.

Figure 6 shows the use of an assistance signal according to another embodiment of the present invention.

Figure 7 shows a positioning system architecture according to an embodiment of the present invention.

5            Figure 8 shows a positioning system according to an embodiment of the present invention.

0964-B954-050304  
"FOE050" +S6B4B60

## DETAILED DESCRIPTION OF THE INVENTION

The invention relates to a low signal-to-noise ratio positioning system. In the following description, numerous specific details are set forth to provide a more thorough description of  
5   embodiments of the invention. It will be apparent, however, to one skilled in the art, that the invention may be practiced without these specific details. In other instances, well known features have not been described in detail so as not to obscure the invention.

### Positioning System Using Assistance Signals

One embodiment of the present invention is shown in Figure 1. At step 100, signals are transmitted from multiple satellites to earth. Then, at step 110, a receiver located on earth receives some of the signals. Next, at step 120, assistance signals are transmitted from a terrestrial broadcast station. Finally, position information is obtained at step 130 by using the satellite and assistance signals.

As shown at step 120 of Figure 1, assistance signals are sent from a terrestrial broadcast station to a receiver to assist the receiver in obtaining positioning information, specifically when the receiver is indoors or when obstacles are in the way. The assistance signals may have various  
20   information in them according to various embodiments of the present invention. In one embodiment, the assistance signals have Doppler frequencies for the satellites.

## Doppler Frequencies

The satellites themselves are traveling very fast in orbit around the earth. Therefore, it is inevitable that the signal sent by the satellite will be altered by the Doppler effect. In practical terms this means, for instance, that if all satellites are transmitting signals at 1575 megahertz then a receiver must locate and receive each of these signals at something other than 1575 megahertz, depending on the direction the satellite is currently traveling.

In one embodiment of the present invention, a terrestrial broadcast station in the general vicinity as a target receiver is chosen where the terrestrial broadcast station is in a more ideal position to receive and calculate accurate Doppler information. This might include, for instance, a broadcast station that has a more powerful antenna or is farther away from obstacles. The broadcast station should be sufficiently close (within 50 to 100 miles, for instance) so that its Doppler shifts are substantially the same as the target receiver and its signals are received from the same satellites. The terrestrial broadcast station, then, is able to locate the satellites and calculate their frequency variations based on the Doppler effect and transmit this information to the target receiver.

In practical terms, this means that a receiver that is obstructed does not have to search the spectrum to locate the correct frequencies for satellite signals varied by the Doppler effect. The assistance signal tells the receiver exactly what frequency to use. Then, the receiver is able to tune to exactly that frequency and no time is expended searching through frequency ranges to

lock in on Doppler affected satellite frequencies and the obstructed receiver may immediately begin to correlate the messages in the signal.

5 This embodiment of the present invention is shown in Figure 2. At step 200, signals are transmitted from multiple satellites to earth. Then, at step 210, a receiver located on earth receives some of the signals. Next, at step 220, a terrestrial broadcast station that is located sufficiently near to the target receiver calculates true Doppler frequencies for the satellites. Then, at step 230, the true Doppler frequencies are transmitted to the target receiver. Thereafter, the target receiver uses the true Doppler frequencies and tunes to those frequencies at step 240, and begins correlating at those frequencies at step 250.

#### Ephemeris Data

10 In one embodiment of the present invention, the assistance signals provide Ephemeris data. Ephemeris data is data that tells the target receiver exactly where each satellite is. Knowing the location of each satellite is essential to calculating the receiver's position. Take, for instance, the case where a receiver is located indoors. Even if the receiver was broadcast Doppler information from a terrestrial broadcast station, the receiver still might not be able to obtain a positional fix because the information telling it where the satellites are was too weak to reach it.

20

This embodiment of the present invention is shown in Figure 3. In Figure 3, signals are transmitted from multiple satellites to earth at step 300. Then, at step 310, a target receiver

located on earth receives some of the signals. Next, at step 320, a terrestrial broadcast station that is located sufficiently near to the target receiver calculates true Doppler frequencies for the satellites. Then, at step 330, the true Doppler frequencies are transmitted to the target receiver.

5           Thereafter, at step 340, it is determined if the signal from the satellite is too weak to receive Ephemeris data. If not, the target receiver uses the true Doppler frequencies and tunes to those frequencies at step 350, and begins correlating at those frequencies at step 360. Otherwise, a terrestrial broadcast station sends Ephemeris data to the receiver at step 370 and the receiver calculates position using the Ephemeris data at step 380.

#### Almanac Data

At any given moment, only a portion of the satellites in a positioning system are currently usable. This is because as the satellites orbit the earth some fall below the horizon. When this happens, the signal from that satellite cannot be used, and is not expected to be used, by the receiver. Almanac data is used to inform a receiver exactly what satellites should currently be used. In one embodiment of the present invention, almanac data is calculated at a broadcast station and sent as part of the assistance signal so that the target receiver does not waste time looking for and trying to receive signals from a satellite that is below the horizon or otherwise  
20   not desirable.

This embodiment of the present invention is shown in Figure 4. At step 400, signals are transmitted from multiple satellites to earth. Then, at step 410, a broadcast station calculates

almanac data for a target receiver. Next, at step 420, the assistance signals, including the almanac data, are transmitted from a terrestrial broadcast station to the target receiver.

Thereafter, the target receiver locates the satellites indicated in the almanac data at step 430.

Finally, position information is obtained at step 440 by using the satellites indicated in the

5 almanac data.

### Navigation Message

10 The navigation message of a satellite can cause a problem for indoor receiving. This is due to the interaction between the correlation code of a satellite and the navigation message broadcast by the satellite. Each satellite broadcasts a high frequency signal (e.g. 1 MHz) of 1's and 0's. This signal is called the correlation code and is a pseudo random string of digital data that repeats at a high bit rate. The navigation message is also a digital message that is broadcast at a much lower bandwidth, several orders of magnitude slower than the correlation data rate. In one implementation, the navigation data is inserted into the correlation data stream as a series of inversions of the correlation data string. For example, a noninverted correlation data string could represent a digital 1 while an inverted correlation data string could represent a digital zero. Thus, for every 100,000 bits of correlation data (when a correlation data string is 100,000 bits in length), only a single navigation message bit is sent.

20

The data system is shown in Figure 5. A repeating series of correlation code bit strings 501A - 501N are transmitted. Periodically, the correlation code bit strings are entirely inverted,

such as at location 501B and 501E. The noninverted strings represent a navigation message bit with a value of 1 while the inverted strings represent a 0 navigation message bit.

For typical outdoor operation of a receiver, this system works adequately because the receiver is able to capture the correlation data relatively easily. At each navigation data transition from one polarity to another (e.g. a 1 bit to a 0 bit or vice-versa) the correlator of a receiver loses its correlation. The receiver assumes that an inversion has occurred, notes the navigation message bit value, and then attempts to lock onto the inverted correlation data string, usually successfully before the next navigation message bit transition.

This does not work as well in indoor uses. There, the receiver may need to correlate for a much longer period of time to achieve an adequate signal to noise ratio. The present invention solves this problem by sending the navigation message bits to the receiver via the terrestrial broadcast station. In this manner, the receiver can predict the inversions and look for the inverted string without ever losing the correlation on the satellite signal. When the transition of the correlation code string is about to occur based on the received navigation message data from the terrestrial broadcast station, the receiver can invert the signal so that the correlator maintains its lock on the correlation code.

The operation of this system is illustrated in the flow diagram of Figure 6. At step 600, the satellite transmits the correlation code signal string to Earth, inverting it periodically to represent navigation message data bits. The target receiver receives the signal from space and the navigation message data from a terrestrial broadcast station at step 610. At step 620, the



receiver correlates the data from the satellite. At decision block 630, the receiver uses the navigation message data from the terrestrial broadcast station to determine if an inversion of the navigation signal is about to occur. If no, the receiver continues correlating the signal at step 620. If yes, the receiver inverts the incoming correlation signal at the appropriate transition time at step 640 so that there is no loss of correlation due to data inversion. The system continues correlating at step 620.

The broadcast station should be relatively close, less than 100 miles away for instance, so that they receive essentially the same signal from the satellite. Using the string sent from the broadcast station, the target receiver is able to know when the inversions will occur, look for the inversions, and hence, the navigation message, while at the same time continuing to correlate on the weak signal.

#### Assistance Signal Architecture

An example of an architecture that may be used to transmit assistance signals is shown in Figure 7. A positioning system antenna 700 receives a satellite signal and transmits it to a positioning system radio frequency (RF) part 710. RF part 710 might include, for instance, conventional means for amplifying the received signal (amplifier), filtering it, and down-converting it to an appropriate intermediate frequency. The amplified and down-converted signal is then applied to a conventional analog to digital converter 720. The output of the converter 720, which represents the digital amplitude samples of the down-converted positioning system signal is stored in a memory 730 for subsequent signal processing.

When appropriate, the positioning system signal stored in memory 730 is transmitted to receiver logic unit 735. A broadcast station 740 having its own antenna 750 also receives signals from satellites and transmits assistance signal 760 to receiver logic unit 735 as well. Receiver logic unit 735 is configured to respond to multiple types of assistance data. In the case where the navigation message is sent in the assistance signal, receiver logic unit 735 might perform a re-inversion of the data when the navigation message inverts, for instance by correlating with a matched filter, a correlater, a Fast Fourier Transform (FFT) unit, or other suitable device.

Receiver logic unit 735 may be a component of a computing device, such as a personal digital assistant, cellular phone, or general purpose computer. Assistance signal 760 may be a provided by a wire, a computer network such as the Internet, or it may be provided wirelessly, such as via a cellular telephone network, wireless data network, a secondary carrier on a transmitter in the commercial broadcast service (TV or AM/FM radio) or by another equivalent means. Memory unit 730 may be used to store data that is not completely transient in nature (i.e., Ephemeris data) and transmit it later to the receiver logic unit 735 when needed.

#### Embodiment of a Positioning System

One embodiment of a positioning system according to the present invention is illustrated in Figure 8. An assistance receiver 812 is coupled to an antenna 811. The assistance data receiver 812 provides navigation bits, Doppler frequencies, time synchronization, ephemeris

data, base station coordinates for 1 ms ambiguity resolution, and pseudo-range differential corrections to a local broadcast network that may be wired, wireless, cellular, or network or internet based.

5           The SPS receiver in the embodiment of Figure 8 comprises an antenna 801 coupled to a processing block 802. The output of processing block 802 is coupled to A/D converter 803 and memory 804 to difference node 805. The output of node 805 is coupled to filter block 806 along with data from the assistance receiver 812. Filter block 806 is coupled to accumulation block 808 and through iteration block 809 to ambiguity resolution block 810.

0984954-050301  
FOUO

15           The output of memory 804 is also coupled to correlation and tracking block 813 which provides output to difference node 805 and to navigation data decoding block 814. The output of block 814 is coupled to memory 816 and to position computation block 815. Ephemeris data and differential corrections data from the assistance receiver 812 is also coupled to position computation block 815 as is memory 816. The position computation block exchanges data with resolution block 810.

20           In operation, the received satellite signal from antenna 801 is inputted to an <sup>RF</sup>~~RF~~ processing section 802 which includes conventional means for amplifying the received signal (amplifier), filtering it, and down-converting it to an appropriate intermediate frequency (IF).

The amplified and down-converted signal is then applied to a conventional analog to digital (A/D) converter 803. The output of the A/D converter, which represents the digital amplitude samples of the down-converted signal is stored in a memory 804 for subsequent signal processing.

5

For low SNR processing of signals, it is desirable to eliminate the effects of cross-correlations from satellites other than the satellite being acquired or tracked. The peak cross-correlation coefficient between all conventional GPS C/A Gold Codes is 65/1023. Additionally, frequency offsets may result in this being even higher.

The output of difference block 805 is applied at filter block 806. Filter block 806 may be comprised of primary and secondary matched filters, or it may be a single structure such as an FFT, or other convolution or correlation device. The output of filter block 806 is applied to non-coherent accumulator 808 which performs a non-coherent detection and accumulation. The non-coherent detection computes some function of the modulus of the output of block 806. The two functions are the modulus and the modulus squared in one embodiment. Typical coherent integration times are on the order of 100 mSec. Non-coherent accumulation would typically be performed on data corresponding to a one second interval of the received signal.

00848954.050301  
T05050.4568860

15

The output of the cross-coherent accumulator is applied to block 809 that iteratively estimates the sub-millisecond pseudorange to the satellite in question. The pseudorange is ambiguous at the one mSec level. It is the function of ambiguity resolution block 810 to resolve the millisecond ambiguity in the pseudorange in a conventional manner. Block 810 takes as its  
5 inputs distances to satellites from a position computation performed at computation block 815.

Assistance data from the aiding receiver 812 communicates the navigation message bits, i.e., telemetry data, Doppler information, base station coordinates for 1 ms ambiguity resolution, PRN numbers and time synchronization information to the filter matched to the C/A and navigation message bits at filter block 806. The aiding SPS receiver also communicates ephemerides and differential corrections (if implemented) to the position computation block 815. Ephemerides may be stored in memory 816 for later use if desired.

The output memory 804 is also connected to the satellite correlation and tracking module  
15 813. In one embodiment, block 813 is a standard SPS correlator. It is aided by the C/A code pseudorange estimates from block 809. The satellite correlation and tracking module 813 is used to derive navigation data from the data stored in memory 804 when the received satellite signal strength is high.

When the signal is weak, such as in an obstructed area (a low SNR condition), Ephemeris data may be stored in memory 816 wherever and whenever it is found by block 813 and block 814 from the SPS receiver. Then it may be used in later conditions where the signal is too weak to allow Ephemeris data to be collected by the SPS receiver. Thus, operation of the aided SPS receiver may continue for a time (typically up to several hours) until the Ephemeris data goes out of date. (Differential corrections may also be stored but these go out of date much more quickly).

The position computation block 815 takes as its inputs Ephemeris data derived from the navigation message decoded in block 814 (and optionally stored in memory 816), or data from the aiding SPS receiver 812 or the stored message in memory 816. Additionally it may use differential corrections from aiding SPS receiver 812 and pseudoranges from the pseudorange ambiguity resolution module 810.

Three points merit special mention at this point. First, the signal correlation and tracking module 813 does not work independently of the filter matched to the C/A code and navigation message bits (block 806). This is because the SNR of the received signal may be inadequate to allow the received signal to be tracked. By operating on the stored data, the causality requirement of the tracking loops is eliminated. Second, this technique does not compute the full cross-correlation function between the data and the locally generated signals. This is because the correlation coefficients are not computed for the uninteresting lags.

Finally, the data memory size can be reduced to the size necessary to store an amount of data that corresponds to the coherent integration period. If, after processing the first data set it is determined that additional data is needed, additional data may be required and stored in memory 804, processed, and the processed results combined with the results of the first processing results for improved accuracy or strength of a statistical test. Similarly, any number of subsequent samples may be acquired, processed, and incorporated into the pseudorange measurements and position computation.

#### Filter Block

In one or more embodiments of the present invention, a filter block, such as block 806 of Figure 8, is used. In one embodiment, filter block 806 is broken into a primary and a secondary matched filter. In operation, the input to the primary matched filter is matched to the product of the C/A code, the telemetry data (navigation bits from the carrier phase reversal signal) and the carrier frequency of the desired satellite signal. This technique differs from techniques that use a filter matched to only the product of the C/A code and a carrier frequency. There are two important differences: First, the technique of using a filter matched to the product which includes telemetry data has the capability to out perform techniques which do not use the telemetry data. This is because the use of the telemetry data allows Longer Coherent Integration of the received signal and subsequently it permits improved post-correlation SNR. Second, the technique of using a filter matched to the product which includes telemetry data differs

mathematically from FFT-based techniques which perform convolutions or correlations on the product of the pseudo random noise (PRN) (the C/A code) and the carrier; these FFT-based convolutions or correlations employ circular convolution which implicitly assumes periodic extensions of the PRN code with the same telemetry bit sign.

5

The output of the primary filter may be viewed as complex correlation coefficients between the data input to the matched filter. This output is applied to a second matched filter. If  $T$  denotes the sample period of the primary filter, the ideal matched secondary filter is given by Bracewell's triangle function, the zeros of which correspond to one C/A code "chip" (define), convolved with the baseband equivalent of the composite of filters in the receiver, sampled at an interval  $T$ . The purpose of this secondary filter is to improve SNR by the complex correlation coefficients prior to non-coherent detection and subsequent accumulation. Loosely, the secondary filter uses information in samples adjacent to the peak correlation coefficient to improve the SNR. More precisely, to maximize SNR, the complex correlation coefficients are applied sequentially to the filter which has as its impulse response the time-reverse, complex conjugate of the above described filter. Practically, this filter may be approximated by a binary approximation to the ideal response. Since both of these operations are linear, they could, of course, be combined in a single filter. However, to do so would result in a more complex implementation.

20



Thus, a low signal-to-noise ratio positioning system is described in conjunction with one or more specific embodiments. The invention is defined by the claims and their full scope of equivalents.

0984854-050301  
T0E050"4S64860